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ESTIMATING PINYON-JUNIPER CORDWOOD WITH THE LINE-INTERSECT METHOD

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ABSTRACT

*Adapts the line intersect method, developed for inventorying logging wastes, to estimating cordwood in singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*). Reviews mathematical basis and provides a field application.*

KEYWORDS: pinyon, juniper, line intersect, cruising, Nevada

Line-intersect sampling resembles the better-known line-intercept method, but the two methods should not be confused. Line-intercept is primarily used for determining cover percentage, but line-intersect is a procedure for sampling with probability proportional to size (p.p.s.). The line-intersect technique was developed by Warren and Olsen (1964) to inventory logging residue. Brown (1971) adapted this technique to sample fuel volume and surface area. A generalized theory on line-intersect sampling is presented by Vries (1973).

The line-intersect method is particularly suited for inventorying woodland trees. It provides a relatively simple way to apply p.p.s. sampling to trees that have irregular (sometimes multiple) stems, and branches all the way to the ground. It can be used to inventory total biomass, wood volumes, fuel loading, and related parameters. In this paper, we apply the method to inventorying pinyon and juniper cordwood in Nevada and then explain how the procedure was developed.

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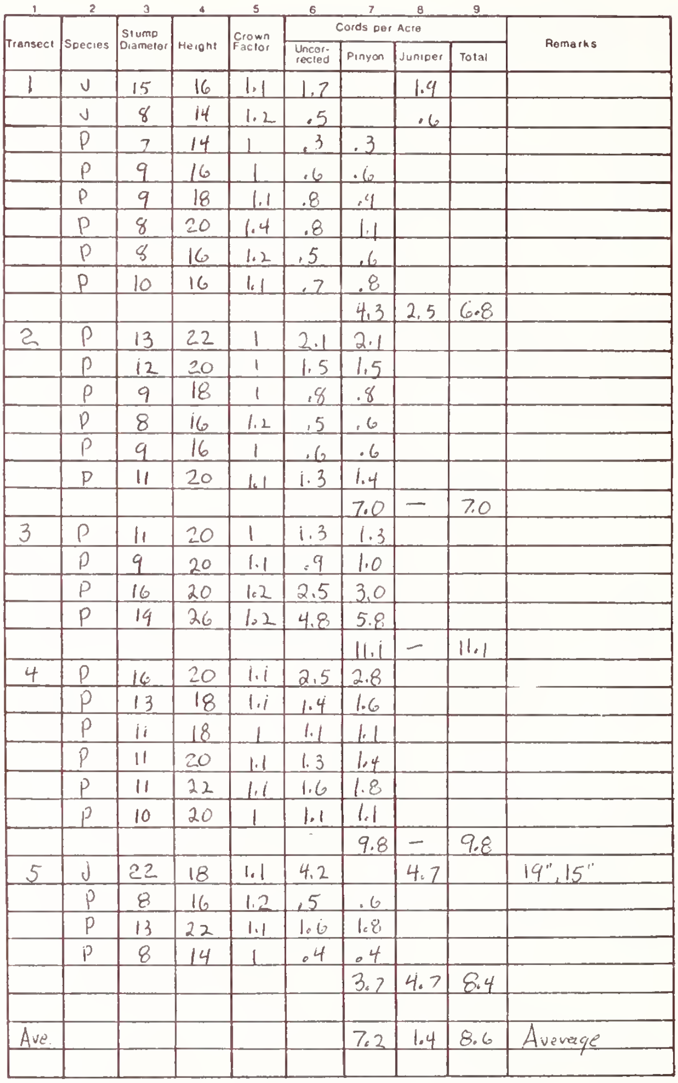
PROCEDURE

The sampling unit is a 100-foot line transect, laid out by compass and tape. For each tree whose crown intersects the line, tally as shown in figure 1: species, diameter at stump height (6 inches) to the nearest inch, height to the nearest even foot, and crown factor.

There is one exception to tallying all trees with crowns over the line: a tree is not tallied if the center of its root crown lies beyond the end of the transect. If the transects are laid out in a continuous series of line segments, this exception applies only to the two ends of the series. Within the series, it makes little difference which transect a borderline tree is tallied in.



1 Transect	2 Species	3 Stump Diameter	4 Height	5 Crown Factor	Cords per Acre				Remarks
					6 Uncor-rected	7 Pinyon	8 Juniper	9 Total	
1	J	15	16	1.1	1.7		1.9		
	J	8	14	1.2	.5		.6		
	P	7	14	1	.3	.3			
	P	9	16	1	.6	.6			
	P	9	18	1.1	.8	.9			
	P	8	20	1.4	.8	1.1			
	P	8	16	1.2	.5	.6			
	P	10	16	1.1	.7	.8			
						4.3	2.5	6.8	
2	P	13	22	1	2.1	2.1			
	P	12	20	1	1.5	1.5			
	P	9	18	1	.8	.8			
	P	8	16	1.2	.5	.6			
	P	9	16	1	.6	.6			
	P	11	20	1.1	1.3	1.4			
						7.0	—	7.0	
3	P	11	20	1	1.3	1.3			
	P	9	20	1.1	.9	1.0			
	P	16	20	1.2	2.5	3.0			
	P	19	26	1.2	4.8	5.8			
						11.1	—	11.1	
4	P	16	20	1.1	2.5	2.8			
	P	13	18	1.1	1.4	1.6			
	P	11	18	1	1.1	1.1			
	P	11	20	1.1	1.3	1.4			
	P	11	22	1.1	1.6	1.8			
	P	10	20	1	1.1	1.1			
						9.8	—	9.8	
5	J	22	18	1.1	4.2		4.7		19", 15"
	P	8	16	1.2	.5	.6			
	P	13	22	1.1	1.6	1.8			
	P	8	14	1	.4	.4			
						3.7	4.7	8.4	
Ave.						7.2	1.4	8.6	Average

Figure 1.--Line intersect tally sheet.

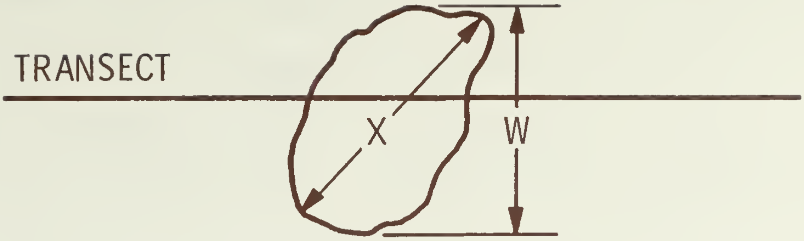


Figure 2.--Crown factor is equal to X/W, the maximum crown diameter divided by the crown spread perpendicular to the transect line. The crown factor is 1.2 in this example.

The crown factor is maximum crown diameter divided by the crown spread perpendicular to the line (fig. 2). The cruiser can estimate the crown factor, height, and stump diameter after measuring a few trees. The stump diameter is measured by diameter tape, not by calipers.

If there is more than one stem at stump height, record the diameters of each stem in the remarks column, as shown for the first juniper in transect 5 in the example (fig. 1). The equivalent diameter is determined by entering the diameters of the two largest stems as D1 and D2 on the nomogram (fig. 3). In the example, the line between 19 inches and 15 inches indicates an equivalent diameter of 22 inches.

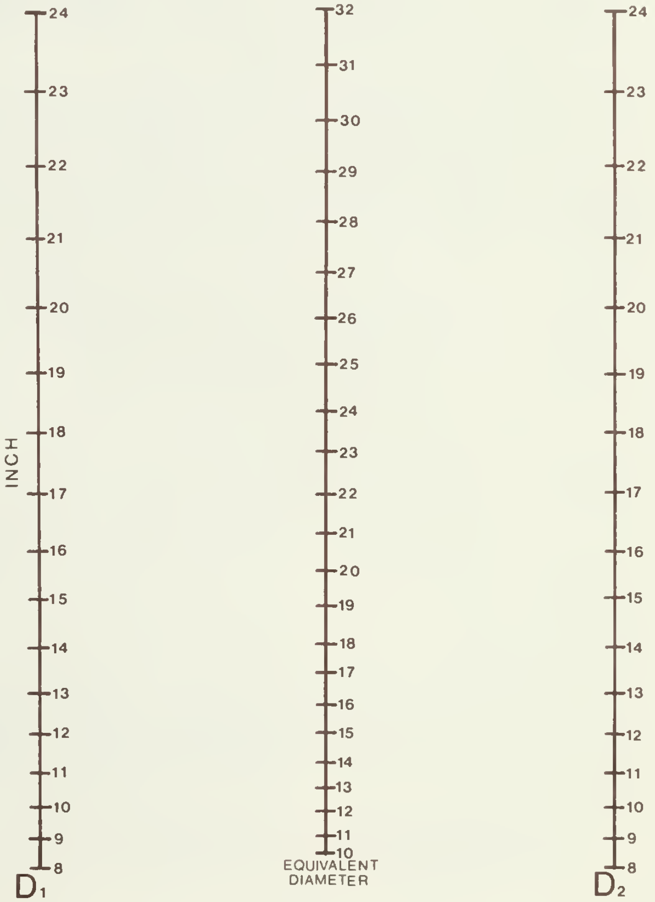


Figure 3.--Nomogram to determine equivalent diameters.

If there is more than one stem at breast height, deduct 2 inches from the actual stump diameter before tallying. This correction is built into the nomogram, so no deduction is made if the tree forks below stump height.

Cords per acre is calculated by the following steps:

1. Enter the appropriate values from tables 1 and 2 in column 6 of the tally sheet. This is the cords per acre represented by each sample tree, based on diameter, height and species.

2. Multiply the values in column 6 by the crown factors in column 5 and enter the corrected values in column 7 for pinyon or column 8 for juniper.

3. For each 100-foot transect, add up the values in columns 7 and 8 to obtain estimated cords per acre. In the example in figure 1, transect 1 has an estimated 4.3 cords per acre of pinyon and 2.5 cords per acre of juniper.

4. Average the transect estimates. In the example, estimated cords per acre is: total, 8.6; pinyon, 7.2; and juniper, 1.4.

Table 1 is based on measurements of 50 pinyons. Table 2 is based on only 26 junipers and covers a narrower range of heights. Table 1 should be used for junipers outside the range of table 2 because it will give better estimates than extrapolations of table 2.

Table 1.--Pinyon cords per acre by line intersect

Dia.	Height (feet)																		
(in.)	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	.2	.3	.4	.4	.5														
7	.2	.3	.4	.5	.6	.7	.8	.9	1.0										
8	.2	.4	.5	.6	.8	.9	1.0	1.2	1.3	1.5									
9	.2	.4	.6	.8	.9	1.1	1.3	1.5	1.7	1.8									
10		.5	.7	.9	1.1	1.3	1.6	1.8	2.0	2.2	2.5								
11		.6	.8	1.1	1.3	1.6	1.8	2.1	2.3	2.6	2.9								
12		.7	.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3								
13		.8	1.1	1.4	1.8	2.1	2.4	2.7	3.0	3.4	3.7	4.1							
14			1.3	1.6	2.0	2.3	2.7	3.0	3.4	3.8	4.1	4.5							
15			1.5	1.9	2.2	2.6	3.0	3.4	3.8	4.1	4.5	4.9							
16			1.7	2.1	2.5	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.7						
17				2.4	2.8	3.2	3.6	4.1	4.5	4.9	5.3	5.8	6.2	6.6					
18				2.7	3.1	3.5	4.0	4.4	4.9	5.3	5.7	6.2	6.6	7.1					
19				3.0	3.4	3.8	4.3	4.8	5.2	5.7	6.1	6.6	7.1	7.5	8.0				
20				3.3	3.7	4.2	4.7	5.1	5.6	6.1	6.6	7.0	7.5	8.0	8.4	8.9			
21					4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.4	7.9	8.4	8.9	9.4	9.9		
22					4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.8	9.3	9.8	10.3	10.8	
23					4.7	5.2	5.7	6.2	6.7	7.2	7.7	8.2	8.7	9.2	9.7	10.2	10.7	11.2	11.7
24					5.1	5.6	6.1	6.6	7.1	7.6	8.1	8.6	9.1	9.6	10.2	10.7	11.2	11.7	12.2
25					5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.6	12.1	12.6
26					5.9	6.4	6.9	7.4	7.9	8.4	8.9	9.4	9.9	10.4	10.9	11.4	11.9	12.4	12.9
27					6.3	6.8	7.3	7.8	8.3	8.8	9.3	9.8	10.3	10.8	11.3	11.8	12.3	12.8	13.3
28					6.8	7.2	7.7	8.2	8.7	9.2	9.7	10.2	10.7	11.2	11.7	12.2	12.6	13.1	13.6
29					7.2	7.7	8.2	8.6	9.1	9.6	10.1	10.6	11.0	11.5	12.0	12.5	13.0	13.4	13.9
30					7.7	8.1	8.6	9.1	9.5	10.0	10.5	10.9	11.4	11.9	12.3	12.8	13.3	13.7	14.2

Table 2.--Juniper cords per acre by line intersect

Dia.	Height (ft.)								
(in.)	12	14	16	18	20	22	24	26	28
8	.2	.5	.7						
9	.2	.6	.8	.9					
10	.2	.6	.9	1.0					
11	.3	.7	1.0	1.2	1.2				
12	.3	.8	1.1	1.4	1.4				
13	.4	.9	1.3	1.6	1.7				
14	.5	1.1	1.5	1.8	1.9	2.0			
15	.6	1.2	1.7	2.0	2.2	2.3			
16	.8	1.4	1.9	2.3	2.5	2.6			
17	.9	1.6	2.1	2.5	2.8	3.0			
18		1.8	2.4	2.8	3.2	3.4			
19		2.0	2.6	3.1	3.5	3.7	3.8		
20		2.3	2.9	3.5	3.9	4.2	4.3		
21		2.5	3.2	3.8	4.3	4.6	4.8		
22			3.6	4.2	4.7	5.0	5.3		
23			3.9	4.6	5.1	5.5	5.8	5.9	
24			4.3	5.0	5.5	6.0	6.3	6.5	
25			4.6	5.4	6.0	6.5	6.8	7.0	
26				5.8	6.5	7.0	7.4	7.6	7.8
27				6.3	7.0	7.5	8.0	8.3	8.4
28						8.0	8.6	8.9	9.1
29						8.5	9.2	9.5	9.8
30							9.8	10.2	10.5

The number of juniper posts per acre can also be estimated by the line-intersect technique, either separately or in combination with cordwood cruising. For each juniper intersecting the line, count the number of posts in the tree and estimate the crown width perpendicular to the line (W in fig. 2). To calculate estimated posts per acre for each transect: divide the number of posts in each tree (n_i) by crown width (W_i), add up the results for the transect and multiply by 435.6.

$$\text{Posts per acre} = 435.6 \quad \sum^{i} \frac{n_i}{W_i}$$

Pinyon Christmas trees per acre can be estimated in the same manner.

CONFIDENCE INTERVAL AND SAMPLE SIZE

Confidence limits (L) and coefficient of variation (C%) are calculated in the conventional way:

$$L = \pm\ s_{\bar{x}} t_{.05}$$

$$C\% = 100 \cdot s/\bar{x}$$

in which $\bar{x}$ is the average, s is the standard deviation, and $s_{\bar{x}}$ is the standard error of the individual transect totals. The standard equation for sample size (N) is:

$$N = \left(\frac{C\%}{E\%} \cdot t_{.05}\right)^2$$

E% is the allowable error. This equation is somewhat difficult to solve because the value of t varies with the degrees of freedom (N-1) and iterative calculations are required. The following equation overcomes this difficulty and is accurate for all values of N greater than two.

$$N = 2.4 + 3.84 \left(\frac{C\%}{E\%}\right)^2$$

For the data in the example (fig. 1):

$$L = 0.82 \times 2.776 = 2.3 \text{ cords per acre}$$

$$C\% = 100 \times 1.84/8.6 = 21.4\%$$

$$N = 2.4 + 3.84\left(\frac{21.4\%}{10\%}\right)^2 = 20$$

These results indicate that the confidence interval of the 5-transect estimate is 8.6 ± 2.3 cords per acre and that 20 transects would be needed to estimate the number of cords in this stand within 10 percent, assuming the 5 transects represent the true variation in the stand. Only 7 transects would be needed for 20 percent error.

DERIVATION OF THE PROCEDURE

The described procedure is based on a variable-width belt transect 100 feet long and "W" feet wide. The width of the transect is, in effect, equal to the crown spread of each tallied tree (W_i) perpendicular to the transect line. Consequently, the equivalent plot area (A_i) associated with each tree is directly proportional to W_i:

$$A_i = \frac{100 \cdot W_i \text{ ft}}{43{,}560 \text{ ft}^2/\text{acre}} = \frac{W_i}{435.6} \text{ acres}$$

The total volume per acre (V/A) estimated by a transect is the sum of the volumes (V_i) of the individual tallied trees divided by their respective equivalent areas (A_i).

$$V/A = \sum^{i} \left(V_i/A_i\right)$$

Substituting $\frac{W_i}{435.6}$ for A_i gives:

$$V/A = 435.6 \sum^{i} \left(V_i/W_i\right)$$

With this equation we could calculate volume per acre if we know W_i and V_i. V_i would be obtained from volume tables and W_i would be measured or estimated directly. Fortunately, we can eliminate the time-consuming determination of W_i in pinyon-juniper cruising. We have found that volume of pinyon and juniper trees is approximately proportional to maximum crown diameter (X_i) at any fixed combination of height and diameter. Consequently, V_i/X_i can be estimated on the basis of height and diameter, and can be tabulated in volume table format.

The equation can be modified to

$$V/A = 435.6 \sum^{i} \left(\frac{V_i}{X_i} \cdot \frac{X_i}{W_i} \right)$$

to eliminate the need for estimating X_i and W_i by substituting the crown factor (X_i/W_i) which can be estimated more quickly and accurately.

Values for 435.6 V_i/X_i are listed in table 1 (singleleaf pinyon) and table 2 (Utah juniper). As outlined in the procedure section, V_i/A_i is obtained by multiplying these values by crown factors.

Tables 1 and 2 are based on regression analyses of data obtained by felling, sectioning, and weighing 50 singleleaf pinyon and 26 Utah junipers on selected sites across Nevada. The equation for pinyon is:

$$\frac{M}{X} = 15.303 - 0.7894H - 3.150D + 0.1715DH + 0.1056D^2 - 0.00347D^2H$$

$$R^2 = 0.96$$

in which M is the weight (lbs) of oven-dry wood larger than 3" diameter in the tree, X is maximum crown diameter (ft), H is total height (ft), and D is diameter (in) outside bark at stump height (6 in). For trees with more than one stem larger than 3 inches diameter at breast height, D was reduced 2 inches for the analysis. For trees with two stems at stump height, D was calculated by

$$D = \left(D_1{}^2 + D_2{}^2\right)^{\frac{1}{2}} - 2$$

The nomogram in figure 3 is derived from the equation. No trees with more than two stems at stump height were sampled, but we believe that if there are more than two stems, the smaller stems would contribute little to cordwood volume.

M/X was converted to V/X by dividing by 2,300 lb/cord. This conversion factor is based on our finding about 70 cubic feet of solid wood (bark excluded) per cord and that oven-dry pinyon weights about 33 pounds per cubic foot. These values of V/X were multiplied by 435.6 and listed in table 1.

The equation for juniper is:

$$\frac{M}{X} = - 8.779 + 2.002H - 0.0793H^2 - 1.897D + 0.04230D^2 + 0.0998HD$$

$$R^2 = 0.98$$

The conversion factor for juniper is 2,100 lbs/cord, based on an estimated 30 lbs per cubic foot of ovendry wood.

The cruising procedure outlined in this paper may be refined as we acquire more data, but we believe the procedure is sound and that few changes will be necessary.

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